

# Waveform Feature Implementation for FRIB LLRF Controllers

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## Introduction

The low level radio frequency (LLRF) controller for the FRIB project is designed to accommodate various cavity and tuner types (See Table 1).

### RF Board

- Direct sampling (38.99 MHz)
- Under sampling (38.99 MHz)
- Non-IQ sampling (31 points)

- Direct synthesis: use band pass filters to pickup fundamental or higher harmonics
- Three variants: supports two frequencies per variant

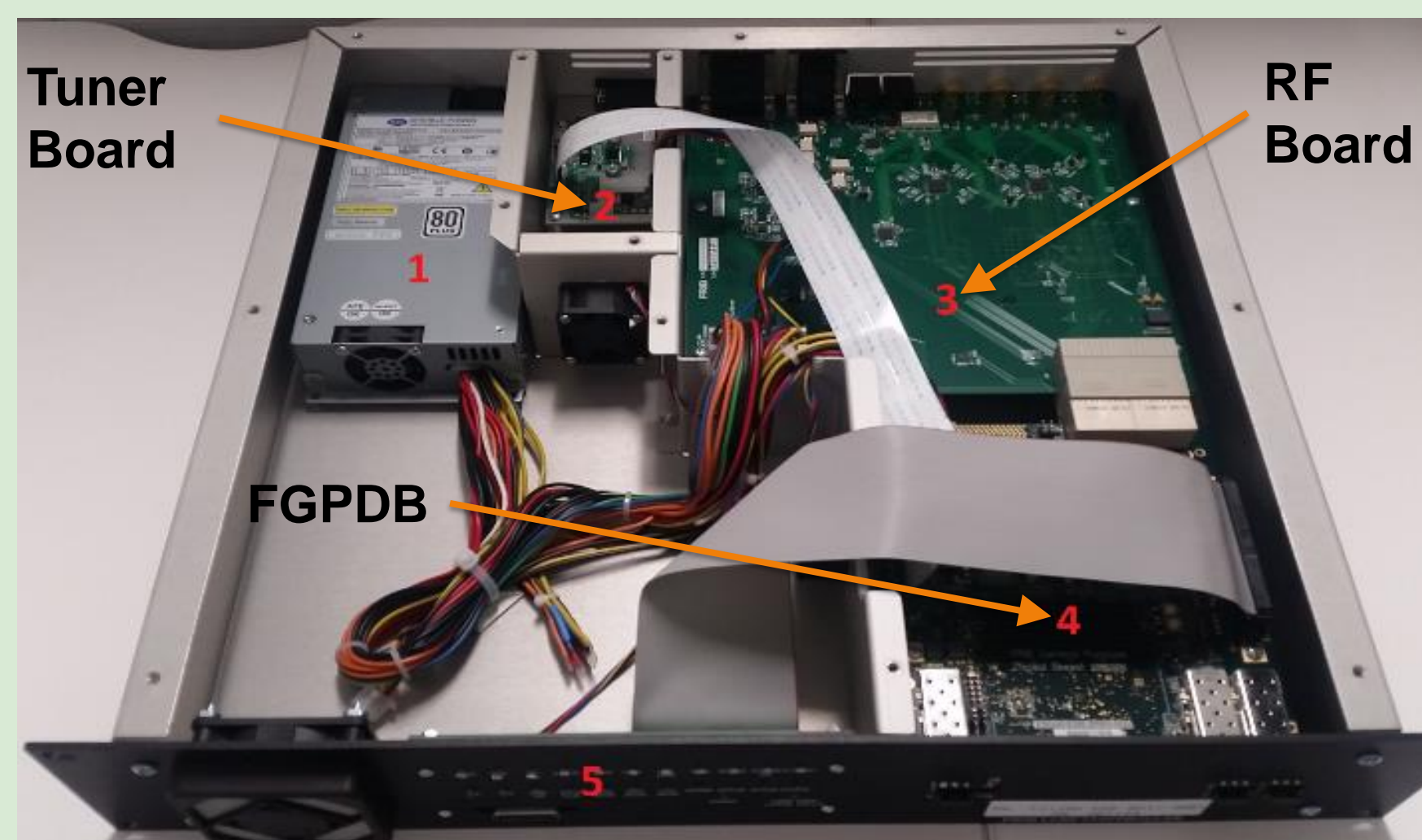
- Spare analog/digital I/Os: 4 AI, 4 AO, 5 DI and 5 DO

### Tuner Board

- Stepper Tuner: 2-phase with micro-stepping; RS-485 interface to 5-phase driver.
- Analog Tuner: pneumatic valves for HWR; error signal to RFQ.

Table 1: FRIB Cavity Types

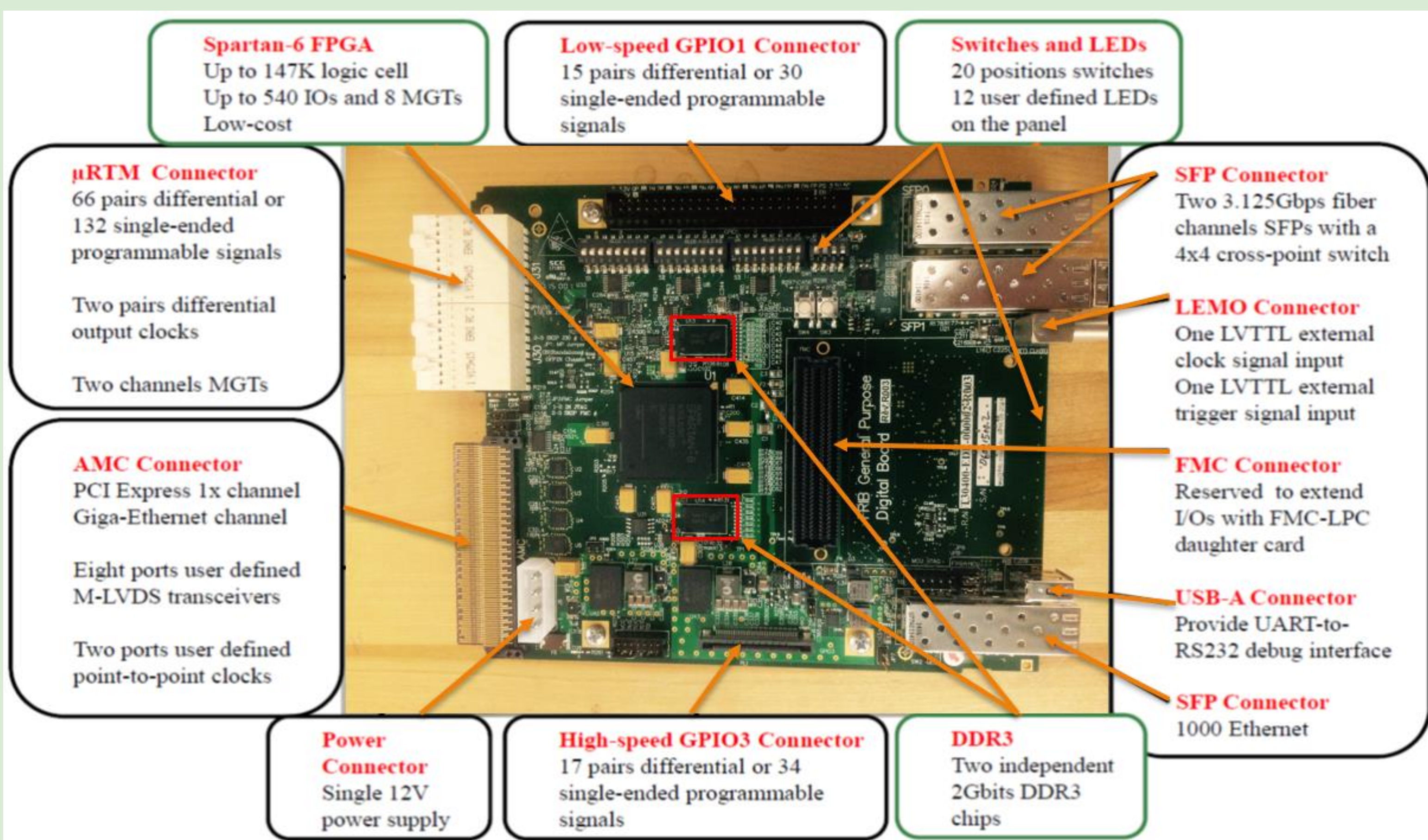
System	Area	Frequency (MHz)	Type	Tuner
MHB F1	FE	40.25	RT	N/A
MHB F2	FE	80.5	RT	N/A
MHB F3	FE	120.75	RT	N/A
RFQ	FE	80.5	RT	temperature
MEBT	FE	80.5	RT	2-phase stepper
QWR	LS1	80.5	SC	2-phase stepper
MGB	FS1	161	RT	5-phase stepper
HWR	LS2/3	322	SC	pneumatic



## FRIB General Purpose Digital Board (FGPDB)

A common digital front-end intended to support multiple systems:

- Low Level Radio Frequency (LLRF, Qty: 372)
- Machine Protection System (MPS, Qty: 80)
- Beam Position Monitor (BPM, Qty: 120)
- Xilinx Spartan-6 XC6SLX150T-FGG900 FPGA, dual 256 MB DDR memory, 16 MB flash, MicroTCA compatible



## Waveform Requirements

- Save important internal data (e.g. the amplitude and phase information of forward/reverse/cavity signals, interlock status, etc.)
- Holds at least one second of fast data at the RF feedback control loop rate (~1.25 MHz, 80.5 MHz / 64)
- Freeze buffer when MPS triggers or internal interlock detected
- Flexibility

### Use cases:

- Freeze the circular buffer when an interlock event happens and read out the fast data to diagnose the problem
- Monitor one or a set of signals at a decimated rate (user settable) while the circular buffer is still running

## Memory Controller Interface

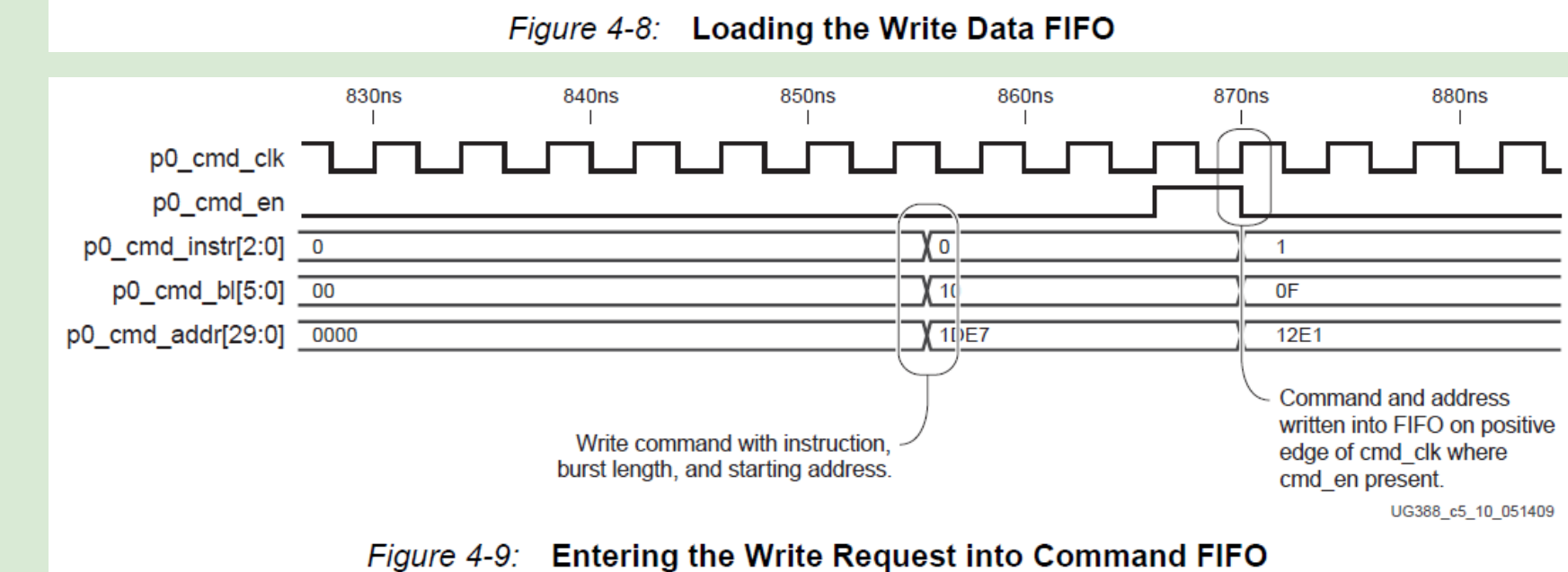
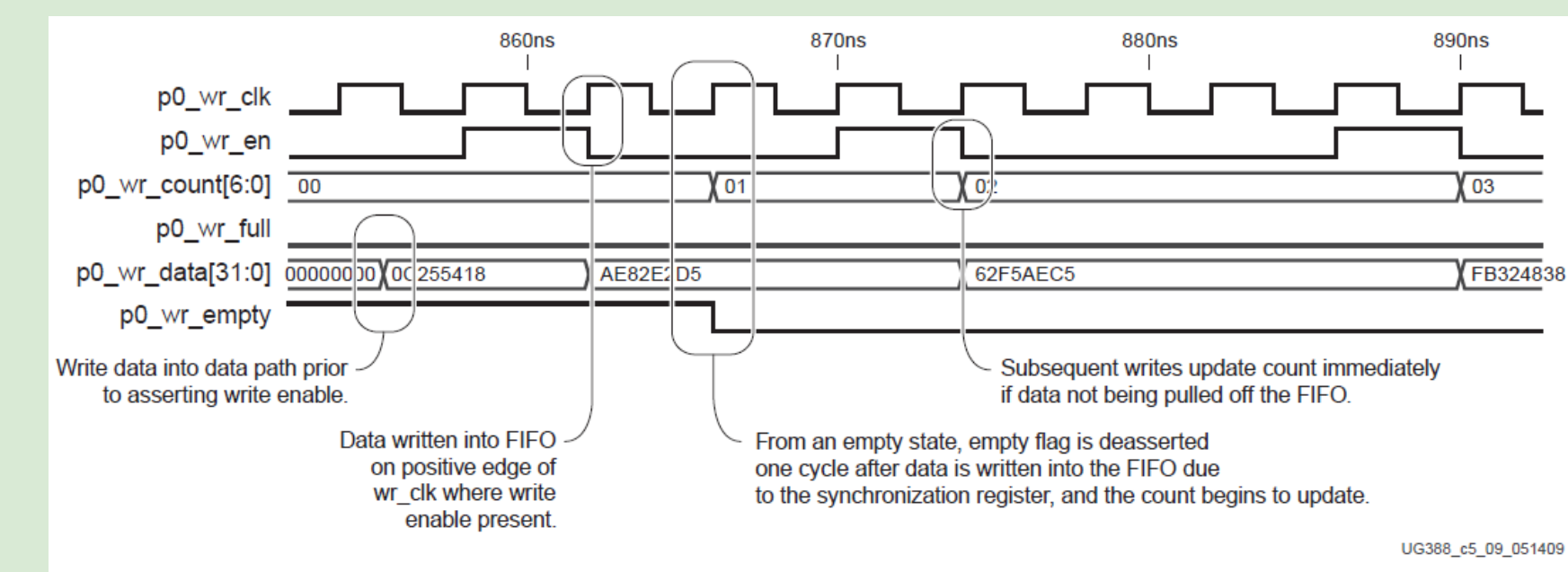
- Native port interface (NPI)  
Write fast data into memory
- Advanced extensible interface (AXI)  
Read/Write data in software

### Memory chip 1:

- Single 32-bit bi-directional AXI port
- For running Microblaze software

### Memory chip 2:

- One 32-bit NPI bi-directional port
  - For writing fast data
- One 32-bit AXI bi-directional port
  - Read only in practice
- Dedicate to circular buffer



Data can be copied through software from chip 1 to chip 2 while the circular buffer is still running to fulfil the second use case.

## Data Organization

### Data structure:

- 16 32-bit registers per sample
- 64 bytes block size
- 4 M samples (256 MB / 64 B)
- ~ 3.3 seconds ( $2^{22} / 1.25 \text{ MHz}$ )

### Pointers:

- *pStart* marks the starting address
- *pCurrent* tracks current sample address
- *pTrig* marks the trigger point

### Flag:

- *flagFull* will be set once the circular buffer is filled;
- *flagFull* resets when buffer starts running for the next time.

Address [Hex]	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	Sample	flagFull	
00000000	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													0	Waveform Variable 1	ID
00000010	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													1	Fwd Phase	2
00000020	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													2	Rev Phase	3
00000030	Tuner Error	Interlock Status	Misc bits	reserved													3	Rev Ampl	4
00000040	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													4	Rev Phase	5
00000050	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													5	Div Ampl	6
00000060	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													6	Rev Phase	7
00000070	Tuner Error	Interlock Status	Misc bits	reserved													7	Div Ampl	8
00000080	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													8	Ampl Setpoint	9
00000090	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													9	Phase Setpoint	10
000000A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													10	Tuner Error	11
000000B0	Tuner Error	Interlock Status	Misc bits	reserved													11	Rev Phase	12
000000C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													12	Misc bits	13
000000D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													13	reserved	14
000000E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													14		
000000F0	Tuner Error	Interlock Status	Misc bits	reserved													15		
00000100	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													16		
00000110	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													17		
00000120	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													18		
00000130	Tuner Error	Interlock Status	Misc bits	reserved													19		
00000140	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													20		
00000150	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													21		
00000160	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													22		
00000170	Tuner Error	Interlock Status	Misc bits	reserved													23		
00000180	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													24		
00000190	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													25		
000001A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													26		
000001B0	Tuner Error	Interlock Status	Misc bits	reserved													27		
000001C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													28		
000001D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													29		
000001E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													30		
000001F0	Tuner Error	Interlock Status	Misc bits	reserved													31		
00000200	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													32		
00000210	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													33		
00000220	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													34		
00000230	Tuner Error	Interlock Status	Misc bits	reserved													35		
00000240	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													36		
00000250	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													37		
00000260	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													38		
00000270	Tuner Error	Interlock Status	Misc bits	reserved													39		
00000280	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													40		
00000290	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													41		
000002A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													42		
000002B0	Tuner Error	Interlock Status	Misc bits	reserved													43		
000002C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													44		
000002D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													45		
000002E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													46		
000002F0	Tuner Error	Interlock Status	Misc bits	reserved													47		
00000300	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													48		
00000310	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													49		
00000320	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													50		
00000330	Tuner Error	Interlock Status	Misc bits	reserved													51		
00000340	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													52		
00000350	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													53		
00000360	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													54		
00000370	Tuner Error	Interlock Status	Misc bits	reserved													55		
00000380	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													56		
00000390	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													57		
000003A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													58		
000003B0	Tuner Error	Interlock Status	Misc bits	reserved													59		
000003C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													60		
000003D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													61		
000003E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													62		
000003F0	Tuner Error	Interlock Status	Misc bits	reserved													63		
00000400	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													64		
00000410	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													65		
00000420	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													66		
00000430	Tuner Error	Interlock Status	Misc bits	reserved													67		
00000440	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													68		
00000450	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													69		
00000460	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													70		
00000470	Tuner Error	Interlock Status	Misc bits	reserved													71		
00000480	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													72		
00000490	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													73		
000004A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													74		
000004B0	Tuner Error	Interlock Status	Misc bits	reserved													75		
000004C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													76		
000004D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													77		
000004E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													78		
000004F0	Tuner Error	Interlock Status	Misc bits	reserved													79		
00000500	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													80		
00000510	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													81		
00000520	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													82		
00000530	Tuner Error	Interlock Status	Misc bits	reserved													83		
00000540	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													84		
00000550	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													85		
00000560	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													86		
00000570	Tuner Error	Interlock Status	Misc bits	reserved													87		
00000580	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													88		
00000590	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													89		
000005A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													90		
000005B0	Tuner Error	Interlock Status	Misc bits	reserved													91		
000005C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													92		
000005D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													93		
000005E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													94		
000005F0	Tuner Error	Interlock Status	Misc bits	reserved													95		
00000600	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													96		
00000610	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													97		
00000620	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													98		
00000630	Tuner Error	Interlock Status	Misc bits	reserved													99		
00000640	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													100		
00000650	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													101		
00000660	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													102		
00000670	Tuner Error	Interlock Status	Misc bits	reserved													103		
00000680	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													104		
00000690	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													105		
000006A0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													106		
000006B0	Tuner Error	Interlock Status	Misc bits	reserved													107		
000006C0	Time Stamp high	Time Stamp low	Fwd Ampl	Fwd Phase													108		
000006D0	Rev Ampl	Rev Phase	Cav Ampl	Cav Phase													109		
000006E0	Div Ampl	Div Phase	Ampl Setpoint	Phase Setpoint													110		
000006F0	Tuner Error	Interlock Status	Misc bits	reserved				</											